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UNCOOLED PRODUCER GAS FOR KETENE MANUFACTURE

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A pilot facility was designed and installed to simulate the transport and use of hot, crude producer gas as a fuel for a ketene manufacturing furnace. Evaluation of this pilot facility has indicated that the transport of hot, crude producer gas experienced significant heat loss (250°C) even with high efficiency insulation. Entrained tar and fly ash rendered valves and process equipment inoperable and created both a process control problem and operational hazard. Savings realized from the improved BTU value of the crude gas versus the (cont)

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20. ABSTRACT (cont)

scrubbed producer gas become small when compared with the potential maintenance costs if the crude gas is used. In addition, equipment suitable for handling and transporting hot, crude producer gas is not readily available.

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INTRODUCTION

Effective management of energy resources essential to the operation of Holston Army Ammunition Plant (HSAAP) has drawn considerable attention and support during the past decade. Rising fossil fuel prices, concern for the availability of these natural resources, and a genuine desire to achieve greater cost effectiveness in overall plant operations prompted the development of a comprehensive energy conservation program during the mid-1970's. Major objectives of this conservation program were to identify potential areas for energy savings at HSAAP and to design and evaluate experimental models for achieving these savings.

In October 1974, the Department of the Army contracted with consultants from DuPont Company's Education and Applied Technology Division to survey all processes and facilities at HSAAP and to prepare technical data packages applicable to each area of the plant. Using information from these surveys, DuPont prepared an energy management report which was published in August, 1975. This report provided recommendations for potential energy savings at both Area A and Area B. One such recommendation suggested substantial savings were available if hot, crude producer gas could be used as fuel for the ketene furnaces. Savings would be realized from a reduction in heat losses which currently occur when the producer gas is cooled and scrubbed at Building 10-A prior to its use in the ketene furnaces at Building 7A.

MMT Projects 5804281 and 5814281, Subtask No. 6, were funded to design, install, and evaluate a pilot facility which would simulate transport and use of the hot, crude producer gas as fuel for a ketene manufacturing furnace. The scopes of work for these projects also provided for the development of a hazards analysis and design criteria for a prototype evaluation if the feasibility of the process was proven by the pilot evaluations.

This Final Engineering Report details information used in the design, procurement, and installation of the pilot equipment. Operational data obtained during the pilot evaluations is discussed along with its relative applicability to any future design and operation of a prototype system. Potential hazards for the process are considered. Conclusions and recommendations concerning the feasibility of the process in a production application are also provided.

BACKGROUND

In August 1975, Messrs. W. L. Viar and J. F. Filliben submitted their report entitled Energy Management Services[1] to the Department of the Army. This report provided technical information concerning the supply and utilization of energy resources essential to the operation of processes and equipment at Holston Army Ammunition Plant (HSAAP). The purpose of the report was to assist Holston Defense Corporation and its management in identifying and evaluating energy savings potential at Area A and Area B.

In Appendix A is an excerpt from the DuPont report dealing specifically with potential energy savings available in the producer gas process at Area A. The consultants claimed that an annual savings of $125K should be realized if Holston were capable of effectively eliminating the scrubbing step from the producer gas manufacturing process. The estimated savings were based upon a producer gas production rate of 150 million cubic feet per month (1.62 m^3/s). The report referred to a number of areas considered in their savings calculations, several of which would be extremely difficult to determine. This writer was unable to substantiate the estimated savings from the available information.

The current producer gas manufacturing process[2] at Building 10-A requires a mixture of low pressure steam and air being forced upwards through a deep, hot furnace bed of bituminous coal. The producer gas which exits the brick-lined Chapman gas producers is a combination of reaction products resulting from the incomplete combustion of the coal and a pseudo-distillation action of the steam and air.

The hot, crude gas which exits the gas producer flows through a brick-lined dust collector and a pitch trap to remove entrained fly ash, soot, and unburned coal dust. The temperature of the gas at the producer discharge averages 1100°F (866.5K) while the gas pressure is essentially atmospheric. Substantial cooling of the gas begins as it enters an un-insulated collector main off the pitch trap discharge. The collector main is operated at a slightly negative pressure as the crude gas is diverted into two vertical scrubber columns. These columns remove residual fly ash from the producer gas vapor and cools the vapor to remove condensable tars. These tars begin to condense as the gas temperature drops below 500°F (533.2K). By the time the producer gas exits the two scrubber columns, its temperature has been reduced to approximately 120°F (322 K). The gas pressure is boosted to 30 inches H_2O (7.5 kPa) and is piped to Building 7-A for use as fuel in the ketene manufacturing furnaces.

The DuPont summary outlined some of the potential pitfalls for implementing their proposal. The consultants noted that major design problems would occur in specifying and procuring equipment suitable for handling and transporting the producer gas at elevated temperatures. Secondly, they cited the potential for cooldown of the gas during transport and the eventual coating problems

if the temperature of the gas were allowed to fall below the condensation temperature of the tar vapors in the gas. Finally the problems associated with the handling of entrained fly ash and coal dust were defined.

In October 1976, an HDC Engineering Department evaluation of the DuPont proposal[3] reaffirmed the concerns expressed by the consultants for the potential design and process related problems. The recommendation was made in this report that a pilot study of the proposal would be necessary prior to any major action being taken to incorporate the idea on a production scale. In Appendix B is a copy of the HDC techical evaluation of the DuPont proposal.

UNCOOLED PRODUCER GAS PILOT PLANT DESIGN AND INSTALLATION

Pilot Plant Process and Equipment Description

The physical and chemical properties of the crude, uncooled producer gas provided significant challenges to the design of a meaningful model with which to evaluate the DuPont energy conservation proposal. The concerns expressed by the DuPont report and the subsequent HDC technical evaluation established the basis for the design rationale.

Figure 1 is a process and equipment diagram for the pilot plant arrangement. Crude, hot producer gas used in the pilot plant was drawn from the top of the Unit 10 dust collector, through a four inch (10.2 cm) diameter suction header, by a Model CB-29-01 blower supplied by American Fan Company. The fan was powered by a twenty (20) horsepower (14.9 kW), 3500 RPM electric motor. The fan boosted the gas pressure from essentially atmospheric to approximately 18 inches H_2O (4.5 kPa) and transported the gas across Building 10-A to an insulated, brick-lined furnace.

The furnace housed an Eclipse Model 248 MVTA (Medium Velocity Tempered Air) burner. The Eclipse burner was a direct-fired type fitted with a Model 2.0 NMP-S pilot designed to maintain a continuous flame. The burner was designed for a maximum flow of 200 ACFM producer gas at 15 inches H_2O (3.7 kPa) differential pressure across the burner nozzle. The burner pilot was fired by a continuous flow of propane and air at 3 inches H_2O (0.7 kPa) and 5.0 inches H_2O (1.2 kPa), respectively.

Combustion air for the continuous propane pilot flame and the main burner was supplied by an Eclipse Model SMA6619-3 air mover. The blower was powered by a 3.0 horsepower (2.2 kW), 3450 RPM electric motor designed to deliver 21000 cubic feet per hour (0.17 m^3/s) at 27.6 inches H_2O (6.9 kPa). BTU input from the pilot averaged 2000 BTU's per hour (0.6 kJ/s). The propane-air mixture in the pilot was ignited by a 10mm ignition spark plug while their flows were controlled by a cross-loaded gas regulator. Power to the ignition plug was supplied by a 120/1/60 primary, 6000 volt secondary transformer.

Control of the Eclipse burner and the continuous propane pilot was maintained by a Model 76057BT30-15 protection flame control package mounted on the control panel. An ultraviolet scanner and heat assembly monitored the burner flame and signalled the presence of a flame to the control package.

Operation of the burner featured the following interlock systems:

1. Operation of the booster gas fan was required prior to operation of the burner. If this fan were stopped for any reason, the pilot burner would similarly shutdown.

2. The booster gas fan discharge pressure had to be maintained between 16 and 21 inches H_2O (4-5.2 kPa) in order for the burner flame to be initiated and maintained.

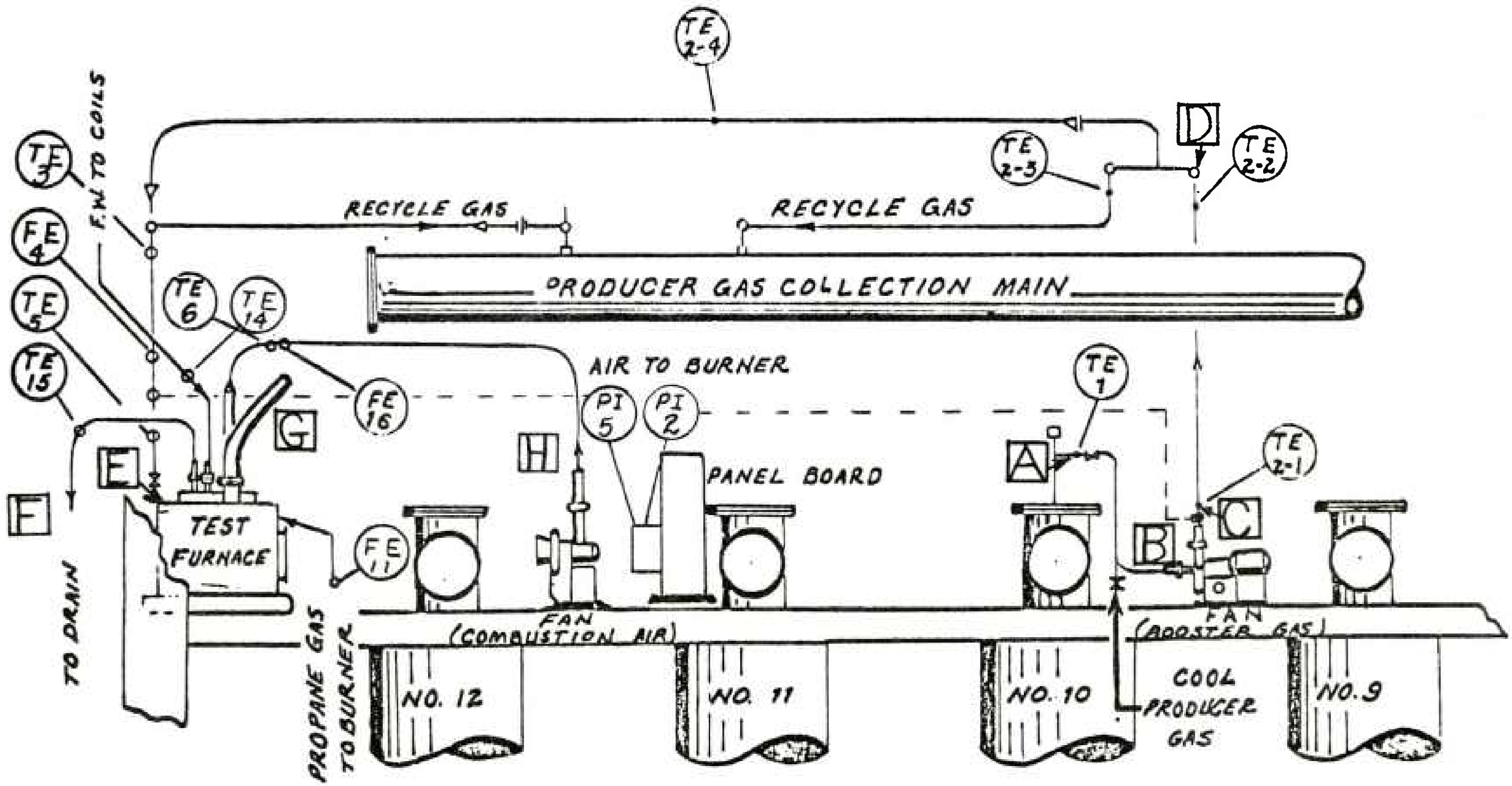

Figure 1. Uncooled producer gas pilot furnace

3. The minimum combustion air pressure was set at 9 inches H_2O (2.2 kPa).

4. Combustion air flow was required to be within the range of 30 to 140 SCFM (0.01-0.07 m^3/s).

5. The maximum furnace temperature was set at 1250°C (1523.15K).

6. A minimum 30 second purge cycle was required for the Eclipse burner both at start-up and following any shutdown.

The heat load generated by burning the propane and producer gases was reduced primarily by a stainless steel cooling coil, using filtered water, and located in the center of the brick-lined furnace. Stack temperatures and visible emissions were monitored.

Two producer gas by-pass pipelines were used to control the flow of the producer gas to the burner. A four inch (10.2 cm) by-pass header was used only during start-up to divert flow to the collector main. A two inch (5.1 cm) diameter by-pass header, located approximately six feet (1.8m) from the producer gas flow control valve was used to "fine tune" the system and provide adequate flow and pressure drop for the burner.

Producer gas process temperatures were monitored primarily by seven Omega Chromel-Alumel thermocouples strapped onto the outside of the producer gas piping. An Omega thermocouple was inserted into the two inch (5.1 cm) diameter piping at the burner inlet to monitor the producer gas temperature. Thermocouples were inserted into the inlet and exit cooling coil piping to monitor heat absorbed by the coil. These temperature monitoring locations are shown on Figure 1.

Insulation of Process Piping and Equipment

Celotemp® 1500 insulation, produced by Celotex, was used to insulate all process piping and equipment in the pilot plant.[4] Celotemp 1500 insulation is a combination of expanded perlite and individual air cells bonded together and reinforced to provide resistance to moisture penetration and crumbling due to impact. Rated for temperatures up to 1500°F (1089K), Celotemp 1500 provides thermal conductivities up to 0.68 BTU/hr/sq. ft./°F per inch thickness.

Three and one-half inches (8.9 cm) of insulation were used on all of the 3 and 4 inch (7.6 and 10.2 cm) diameter piping while three inches (7.6 cm) of insulation was used on the smaller process piping. The insulation was installed in two layers individually wired in place and covered with an aluminum faced roll covering. Pre-formed joints of insulation were used at 90 degree elbows. The insulation was sealed to prevent air leakage.

Two inch (5.1 cm) block insulation was used on the gas booster fan while three inch (7.6 cm) block insulation was installed on the furnace.

Insulation was not required for the combustion air piping or the flue gas discharge piping.

Pre-Operational Safety Inspections

A five-man team was appointed by HDC management[5] to conduct pre-operational safety inspections of the pilot facility. Special precautions were necessary due to the direct linkage of the pilot plant with the Building 10-A production equipment, specifically the gas collector main and the Unit No. 10 dust collector. Deficiencies noted by the inspection team were corrected prior to operation of the pilot plant. Subsequent inspections of the pilot plant did not produce any other deficiencies.

EXPERIMENTAL: BASELINE INFORMATION

Cold, Scrubbed Producer Gas Properties

Producer gas samples were obtained to establish baseline data for the cold, scrubbed gas. The samples were analyzed by gas chromatography to determine their composition. BTU values were calculated based upon their combustible components. The analyses of the five samples and their calculated BTU values are shown in Table C-1 of Appendix C.

Additional calculations were made, using the average analyses from the five samples, to determine the density, specific heat, and viscosity of the gas at the baseline temperature of 120^{o}F (322 K). These calculated values are included in Table C-2 of Appendix C.

Emissions Restrictions and Calculations

In order to accommodate the stack gases from the pilot furnace, a six inch (15.2 cm) diameter header was installed from the furnace to the stoker vent stack of the Unit No. 12 Chapman producer. HDC management and EPA accepted this arrangement with the understanding that the following conditions could be met:

1. Emissions from the test furnace would not exceed limitations of the existing stack permit (Permit No. 010646P, dated 5-15-80, Bldg. 10, Area A; source reference No. 82-00018-16 EMS #016).

2. Emissions would meet all applicable provisions of the TAPCR; Chapter 1200-3-5 Visible Emissions. 1200-3-5-.01(1).

   Opacity must not exceed 20 percent for an aggregate of more than 5 minutes in any one hour or more than 20 minutes in any 24 hour period.

3. Particulate matter shall not exceed 2.0 pounds per hour (0.25 g/s).

4. Fugitive dust must not exceed an opacity of 10 percent for an aggregate of 15 minutes in any 24 hour period.

Anticipated particulate emissions for the pilot plant were calculated based upon the maximum burner flow condition of 200 ACFM. The resulting 1.68 pounds per hour (0.21 g/s) was well below the previously stated limit.

Problems of excessive fugitive dust and high opacity were considered improbable. Hot, raw gas burned during the flaring operations when a producer is started-up simulates the pilot process, and at no time has this flaring produced visible emissions. Therefore, the test furnace was expected to operate within the required limits.

Operation of the pilot facility under the existing permit was investigated

with the Tennessee Air Quality Control Representative who verified that a new permit would not be required if HSAAP felt the above conditions would be met.[6]

EXPERIMENTAL: OPERATIONAL EVALUATION

Initial Pilot Plant Start-Up

The pilot plant was initially started-up using cool, scrubbed producer gas from the Building 10-A secondary scrubber column. The cool gas was transported to the system through a two inch (5.1 cm) diameter, uninsulated header attached to the suction of the gas booster fan. A four inch (10.2 cm) gate valve isolated the cool gas system from the hot crude gas connection on the top of the Unit 10 dust collector. Operation with the cool, scrubbed gas provided an opportunity to study the instrumentation and control systems of the pilot plant and to identify and correct deficiencies without the additional problems of contamination from the crude gas.

Start-Up Problems and Their Correction

The following major problems/deficiencies were identified and corrected during the pilot plant operations with the cool gas:[7]

1. Wiring defects in the interlock systems prevented operation of the pilot burner. These defects were corrected.

2. The pressure regulator in the propane system was factory fitted with an improperly sized orifice and pressure delivery spring. The system was designed to reduce the propane pressure from 4 psig (27.6 kPa) to approximately 3 inches H_2O (0.7 kPa) at a flow of 10 CFH (7.9E-05 m^3/s). This would have required a one-eighth inch (0.3 cm) orifice with a properly sized spring. Instead the system was fitted with a half inch (1.3 cm) orifice and a spring designed to deliver 10-15 inches H_2O (2.5 - 3.7 kPa) pressure. A two week delay occurred while waiting on replacement parts from the factory.

3. The control valve for producer gas flow to the Eclipse burner was improperly fitted with an 80 psig (551 kPa) spring loaded actuator, whereas the original design required a 15 psig (103 kPa) actuator. The system was redesigned with a Bailey positioner attached to the 80 psig (551 kPa) actuator and a 0-30 psig (0-207 kPa) regulator for control of the positioner.

4. Flow recorder modules for the propane and producer gas flows were defective throughout the evaluations. New modules were ordered from Chessell; however, the delivery schedule was two months. Therefore, the pilot plant was operated without the benefit of a direct read-out on these flows. Using the flow equations for the two flowmeters and pressure drop readings across their elements, flows were calculated for both systems.

Cool, Scrubbed Gas Operation

The pilot plant was operated on four separate occasions, totaling 13 hours,

using the cool, scrubbed gas from the secondary scrubber column. The temperature of the cool gas during these runs averaged 113^{o}F (318K). The longest continuous run using the cold gas lasted 5½ hours. Data from this run is shown in Table D-1 of Appendix D.[8]

It was discovered during these runs that the 4 inch (10.2 cm) diameter by-pass was required only during start-up. It was necessary to close this piping off completely during normal operation in order to maintain sufficient discharge pressure on the gas booster fan for proper operation of the Eclipse burner. As shown in Table D-1 of Appendix D, the discharge pressure on this fan (PI-2) averaged 20.5 inches H_2O (5.1 kPa). Taking into consideration pressure drop across the system to the flow control valve and the pressure drop across the one inch (2.54 cm) Annubar flowmeter, the producer gas flow averaged 80.4 ACFM (0.038 m^3/s) for this 5½ hour run.

The ΔT for the furnace cooling coil averaged 13°F (7.2 K) with an average water flow of 23 GPM (1.5E-03 m^3/s). The furnace exhaust temperature averaged 769^{o}F (682K) during this run. No visible emissions were noted.

Operations Using Hot, Crude Producer Gas --test 1

The initial pilot plant operation using the hot crude gas from the Unit 10 gas producer lasted 3 hours. Data from this run is shown in Table D-2 in Appendix D.

The producer gas temperature exiting the Unit 10 dust collector into the pilot system reached a maximum of 1018^{o}F (821 K). Substantial leakage occurred around the booster fan shaft seal, especially during start-up and initial heat up of the system. This leakage diminished as the run continued but at no time did it stop.

The 4-inch (10.2 cm) diameter by-pass was closed completely shortly after start-up. The discharge pressure on the fan reached a maximum of 17.9 inches H_2O (5.6 kPa). This yielded a pressure drop across the Eclipse burner of 8.2 inches H_2O (2.0 kPa) and a calculated producer gas flow 88.3 ACFM (0.42 m^3/s).

Severe heat losses occurred in the area of the gas booster fan with a ΔT of 366°F (203 K) at maximum conditions. This ΔT relates to a heat loss of approximately 74,000 BTU/hr (21.7 kJ/s). Similar heat losses were to occur again and again during later runs. This problem will be discussed in more detail later in this report.

Operations Using Hot, Crude Producer Gas --test 2

The pilot furnace was next operated for 2½ hours using hot, crude producer gas. Data from this run is in Table D-3 of Appendix D.

Conditions similar to those observed during the first run were observed with severe leakage again occurring around the booster gas fan shaft. A very slow heat-up cycle also occurred.

The maximum temperature of the producer gas entering the pilot system was 1039°F (833K). A severe ΔT occurred across the booster fan and the system as a whole. It was planned to operate the system until steady-state conditions were achieved, however, the operation tripped and would not restart. An investigation which followed found severe accumulations of fly ash, tar, and soot throughout the system especially in the small diameter piping at the burner. It was determined that the shutdown occurred when an operator, who was cleaning the Unit 10 pitch trap, stirred up fly ash in the dust collector. The system was steam cleaned and prepared for start-up.

The hot crude producer gas stream was sampled during this run. Gas chromatography analyses of these samples are shown in Table D-4 of Appendix D. Included in this attachment are the calculated BTU values for each sample as well as a calculated average. One cold gas sample was obtained from the regular production system for comparison purposes. The cold gas had a calculated BTU value of 132.5 BTU/ft^3(4.9 MJ/m^3) versus 153.96 BTU/ft^3 (5.7MJ/m^3) for the hot gas. The difference in these values is the result of a difference in the hydrogen, methane, and carbon monoxide contents of the two gas streams.

Operations Using Hot, Crude Producer Gas--test 3

During the next test, the pilot furnace was operated for 2½ hours before a shutdown occurred. Numerous efforts to restart the system failed. Table D-5 in Appendix D lists data recorded for this run.

Piping adjacent the burner was dismantled and inspected. Fly ash accumulations in this area had completely blocked the flow of gas to the burner. Similarly tar build-up had completely plugged the drip leg in this area and had formed a coating ¼ inch (0.64 cm) thick on all of the piping. Tar solidified on the knife gate of the 3 inch (7.6 cm) Fabri-Valve prevented its actuation. The fly ash was blown out of this piping using steam and plant air. Tar was chipped from the Fabri-Valve and its actuation restored.

An inspection of the inside of the furnace revealed severe accumulations of tar on the cooling coil, furnace walls, and exhaust header. The bottom of the producer gas nozzle in the burner was coated with tar which could not be removed. Finally, a large cinder which surrounded the propane pilot flame inlet was removed.

The shutdown and subsequent failure to restart the burner was caused by the cinder surrounding the pilot flame port and the severe fly ash content in the producer gas. It was hypothesized that during operation of the burner, tar and fly ash falling onto the pilot flame port would extinguish the flame or at least hide the flame from the U. V. scanner.

The entire system was again steam cleaned. The piping and furnace were reassembled for future operation.

Operation Using Hot, Crude Producer Gas--test 4

The longest continuous operation of the uncooled producer gas pilot plant using hot, crude gas lasted 9½ hours. Table D-6 in Appendix D lists the data from this run.

The operation was stopped on only one occasion. That occurred when the Limanometer pressure monitor of the gas booster fan received a false high pressure signal. The system tripped but was restarted with essentially no lost time.

The system achieved steady-state conditions after approximately four hours of operation. At this time the gas temperature entering the pilot plant was 985°F (802.6K) while the gas entering the burner was 540°F (555.4K). Flow to the burner was approximately 110 ACFM (0.05 m^3/s). Propane flow to the burner pilot was 14 SCFH (1.1E-04 m^3/s).

Table D-7 in Appendix D lists the gas chromatography analyses of the hot producer gas used in this run. The BTU value of the hot gas averaged 153.15 BTU/ft^3 (5.7 MJ/m^3) compared with the BTU value of the cool producer gas on this day of 128.95 BTU/ft^3 (4.8 MJ/m^3).

Following this run, the pilot plant was again dismantled, inspected, and cleaned. The tar accumulation in the piping had increased slightly and the operation of the Fabri-Valve knife gate was again impaired by solidified tar. Fly ash and soot were again present in all of the smaller piping. Inspection of the furnace coil and burner throat found accumulations of tar and fly ash. A cinder had again formed around the pilot flame inlet port. The system was cleaned and prepared for start-up.

Final Operation of the Pilot Plant --test 5

The final operation of the uncooled producer gas pilot plant lasted only 1½ hours and was stopped when a fire developed in the gas booster fan. Table D-8 lists gas chromatography analyses of samples obtained prior to the fire.

The booster gas fan and adjacent piping were dismantled to assess the damage from the fire. Much of the covering of the fan insulation had been consumed by the fire. Similarly, the gaskets on the fan housing were destroyed and the housing itself was damaged. Operation of the fan following the fire produced severe vibration, indicating warpage of the housing, impeller, and possibly the fan shaft.

The suction of the gas booster fan was coated with a layer of tar and fly

ash 3/8 in (0.9 cm) to 1/2 inch (1.27 cm) thick. Large chunks of tar and fly ash were removed from the fan and adjacent piping. In the 90° elbow just above the fan, the pipe diameter, which was normally 4 inches (10.2 cm), had been reduced by at least 50 percent. The 4-inch (10.2 cm) gate valve which isolated the fan from unit No. 10 would not close completely, allowing crude gas to leak through.

The decision was made that future operation of the pilot system would be hazardous and would only serve to reinforce the information already recorded. In addition, the damage to the fan was extensive and could require replacement. Funds were not available for this purpose.

EXPERIMENTAL: PROCESS DATA ANALYSIS

Crude Producer Gas Physical Properties

Crude producer gas analyses determined from samples are assumed to be typical for this process gas stream. Based upon the component averages for this sample data, physical properties such as gas densities, specific heats, and viscosities were calculated as a function of temperature. Table E-1 in Appendix E lists these calculated values.

Pilot System Material Balance and Energy Calculations

A material balance was calculated based upon the steady-state conditions achieved during the pilot system operations. Assumptions were made regarding the producer gas losses around the booster gas fan shaft. The total flow from the Unit No. 10 gas producer was obtained from the booster fan curve. Table E-2 in Appendix E lists the material balance (English and SI units) based upon these criteria.

Major conduction and radiant heat losses occurred throughout the pilot system. The driving force created by the extreme temperature difference of the hot producer gas versus the external insulation surface temperature was responsible for these losses. Air velocities averaging 0-5 miles per hour (0-2.2 m/s) compounded the problem by increasing the normal losses by approximately eight percent.

The area of major concern for heat losses occurred in the booster gas fan plus its suction and discharge piping. Calculated heat losses for this area totaled 74029 BTU/hr (21.7 kJ/3) while an average temperature drop of 300 $^{\circ}$F (422K) was measured across the gas booster fan.

BTU Value Comparison for Crude Producer Gas Versus Scrubbed Producer Gas

The average BTU value of the crude producer gas samples was 153.15 BTU per cubic foot (5.7 MJ/m^3) while the cold, scrubbed producer gas analyzed 128.95 BTU per cubic foot (4.8 MJ/m^3). Table E-3 in Appendix E provides a comparison of the component analyses of these two gas streams. Also shown are the calculated BTU values for each "active" component. The hydrogen, methane, and carbon monoxide contents in the crude gas were significantly higher than in the scrubbed gas stream, thus explaining the higher BTU value of the hot gas. Also note that the oxygen content of the scrubbed gas is approximately five times that of the hot gas.

The differences in component analyses for the two gas streams were caused by the injection of steam and dilution liquor into the collector main and scrubber column. This action significantly increased the nitrogen and oxygen levels in the producer gas stream and diluted some of the other components. Ethane and ethylene levels remained relatively unchanged.

Stack Emissions

Throughout the pilot operation, close visual checks of the Unit No. 12 stoker vent stack were made to determine if particulate emissions were present. Attempts were made, without success, to obtain samples of the stack gas. At no time during the pilot plant operation were any visible emissions observed. Calculations of particulate emissions were made based upon a maximum producer gas flow to the pilot furnace of 117.6 ACFM. Based upon this flowrate, 0.99 pounds of particulates per hour (0.12 g/s) would be exhausted to the atmosphere. As stated earlier in this report the maximum allowable emission rate was 2.0 pounds of particulates per hour (0.25 g/s).

Equipment Evaluations

A major task of this MMT pilot work was to assess the impact of the hot, crude producer gas upon piping, valves, fittings, and process equipment. Therefore at the conclusion of the pilot work, the pilot equipment was disassembled and inspected. Below is a listing of major items in the pilot plant and the effect which the crude hot producer gas had upon their final condition:

1. Gas Booster Fan: The fan suction was coated with a 1/2 inch (1.27 cm) thick layer of hardened tar and fly ash. The fan turbine was blackened by a thin layer of tar and fly ash and the one inch (2.54 cm) drain nozzle on the fan housing was blocked by hardened tar. Tar coated the interior of the housing forming a half inch (1.27 cm) layer near the fan shaft seal but not blocking the seal. The fire during the last run damaged the gaskets on both sides of the fan housing and most of the block insulation on the outside of the housing. The fire also damaged the fan turbine and warped the fan housing and shaft.

2. Gate Valves: The operation of the four inch (10.2 cm) gate valves on the fan suction and in the by-pass piping was greatly inhibited by accumulations of hardened tar and fly ash. Neither valve would close completely, therefore allowing seepage of gas into adjacent piping even when the pilot plant was not operating. The two inch (5.1 cm) valves on the by-pass piping and the flow control loop were similarly blocked by hardened tar which inhibited their operation.

3. Flow Control Valve (Fabri-Valve, Sliding Gate): The sliding gate in this three inch (7.6 cm) flow control valve was frozen in position by a ¼ inch (0.64 cm) thick layer of hardened tar. The gate could not be opened even with 80 PSIG (551 kPa) air on the spring-loaded actuator. It should be noted that on several occasions during operation of the pilot plant, this valve failed open when the plant shutdown because of the tar buildup. This introduced a significant hazard to the operation.

4. Eclipse Burner: The throat of the burner was coated with a thin layer of tar and fly ash. Several of the inlet air ports were completely blocked by the tar. The producer gas inlet nozzle was approximately 40 percent blocked by a layer of tar lying on the bottom of the 1 inch (2.54 cm) diameter pipe. Around the pilot flame inlet, a cinder had formed created by the tar dripping from the producer gas nozzle and the fly ash in the gas stream.

5. Furnace Walls and Cooling Coil: The furnace walls were covered by a thin layer of tar and soot from the combustion of the propane and producer gases. Similarly the cooling coils were fouled by a layer of tar. Cinders ranging in size of 1/2 inch (1.27 cm) down to small grains were present on the furnace floor.

6. Piping and Fittings: Severe tar accumulations were present throughout the system. In a 90^{o}elbow on the gas booster fan discharge, the four inch (10.2 cm) diameter piping was reduced by approximately fifty percent. Coatings were somewhat less in straight runs of piping; however, accumulations were quite severe at flanges, directional changes, and at piping diameter reductions. Coating in the two inch (5.1 cm) and one inch 2.54 cm) piping adjacent to the burner was quite severe.

As a general assessment of the problem of using crude gas, it was quite apparent that transport of the hot gas, even for short distances, would not be feasible. The availability of equipment suitable for such a task is quite limited based upon the lack of interest on the part of vendors to bid on the pilot equipment. Secondly, transport of the gas introduces problems of tar and fly ash accumulations which would not easily be solved. The operation of the pilot plant with hot, crude gas was approximately 18 hours, yet much of the piping, valves, and process equipment were rendered useless even in this short time. It is recognized that some of these problems were magnified by the smaller equipment; however, it is this writer's opinion that maintenance costs to provide continuous operation using the hot gas would be very expensive.

Hazards Identification

Two major concerns must be addressed with regard to operation of the pilot plant with the hot crude gas. The fire in the gas booster fan could have been much worse had it propogated through the piping and into the collector main. A lack of safety equipment specifically in the area of this fan was a significant oversight. An elaborate flame monitoring system would be required for a prototype or a production system.

The failure of the control valves and other process equipment under these extreme temperature conditions is considered quite hazardous. As stated earlier, the three inch (7.6 cm) flow control valve in the producer gas feed piping failed open on several occasions due to tar build-up on the gate and in the gate channel. No incidents occurred, however, as the result of this

valve's failure to close. An elaborate and redundant system would be required to assure proper functioning of the flow control system.

Prototype Scale-Up Considerations

Based upon the process and equipment related problems discussed in this report, scale-up of the hot, crude producer gas process for prototype or production purposes would not be feasible. The savings resulting from retention of BTU valve of the hot gas would be quickly lost in maintenance costs and equipment replacement costs. Also considered in this judgement is the limited availability of suitable process equipment for transporting the hot gas and the inflexability of the process with regard to linking it directly with the ketene manufacture in Building 7-A.

CONCLUSIONS

1. Hot, crude producer gas from the Chapman gas producers could not be transported for even short piping distances without experiencing significant losses in temperature. Temperature losses averaging 450^{o}F (505K) were recorded for the pilot system with two-thirds of these losses occurring in the area of the gas booster fan. Similar temperature losses should be anticipated for prototype or production systems.

2. The double-layered thicknesses of Celotemp high temperature insulation (rated for 1500^{o}F) were inadequate for preventing the significant heat losses which occurred in the pilot system. The heat losses resulted primarily from the difference between the producer gas and the outside ambient air temperature. Additional insulation thickness may have reduced these heat losses somewhat; however, use of the additional insulation was considered neither feasible nor economical.

3. The producer gas booster fan was inadequate for handling and transporting the hot, crude producer gas. This conclusion was prompted by multiple failures of the high temperature gasketing used on the fan housing and severe producer gas leakage which occurred around the fan shaft seal. Leakages in these areas were minimized but were never stopped.

4. Entrained tar and fly ash in the hot, crude producer gas rendered valves and process equipment inoperable and created both a process control problem and an operational hazard. Removal of these contaminants early in the process would be required for prototype or production scale operations. Otherwise, maintenance costs would be expensive and continuous operation would be impossible.

5. Savings realized from the improved BTU value of the crude gas versus the scrubbed producer gas are negligible when compared with the potential maintenance costs when using the crude gas. Operation using the crude gas cannot be justified for this reason.

6. Equipment suitable for handling and transporting hot, crude producer gas is not readily available. This was evidenced during the procurement phase of this project when many vendors showed no interest at all. Others anticipated the problems which led to the failure of the gas booster fan to perform properly. Similar equipment procurement problems would be anticipated for a prototype or production process involving the hot crude producer gas.

RECOMMENDATIONS

It is recommended that crude uncooled producer gas not be considered for use as fuel in ketene manufacturing furnaces. Problems with tar and fly ash contamination of the hot, crude gas make transport of the gas expensive and generally nonfeasible even for short distances. Energy savings resulting from the recovery of normal heat losses in the producer gas are quickly diminished by potential maintenance and capital expenditure costs. Continuous operation would be impossible, thus limiting the overall production capability of the plant. Hazards considerations for the system also make this process unattractive.

REFERENCES

1. J. F. Filliben and W. L. Viar, "Energy Management Services Report," DuPont Education and Applied Technology Division (1975).

2. HDC Standing Operating Procedure No. 7400-0010-A, Manufacture of Gas, Building 10, Area A (1972).

3. P. E. Justus, "Evaluation of DuPont Energy Conservation Proposal for Gas Producer Process," Memorandum to Mr. L. A. Freyre, dated October 26, 1976.

4. "Thermal Insulation," Piping Handbook, Fifth Edition, pp. 6-1 through 6-21.

5. J. W. Hoard, "Inspection Team - MM&T Project 5XX4281," Memorandum dated September 8, 1982.

6. P. E. Justus, Report of Telephone Conversation, "Stack Emission Permit Question - Hot Producer Gas Test Furnace," Conversation with Mr. Jim Haynes (Tennessee Air Quality Control) dated February 10, 1981.

7. HDC Research and Development Notebook, pp. 1-9.

8. P. V. Simerly, "Analyses of Producer Gas," Memorandum to J. D. Hammonds, dated January 28, 1983.

APPENDIX A

PRODUCER GAS GENERATION,
PROCESSING, AND FIRING

Producer gas is scrubbed and cooled before it is delivered to the Ketene Furnaces to condense tar vapors and separate the tar and flyash from the mixture.* Clean producer gas and burnable tar are then transported to different furnaces for firing.

It is proposed that the cooling and reheating processes of the two fuel streams be avoided by burning the original mixture discharged from the producer dust collector directly in the Ketene Furnaces. This would require fundamental changes in the system concepts. For example, any entrained fly ash would be passed with the fuel to the Ketene Furnaces and settle there. It would have to be cleaned out periodically, and abrasive effects would have to be considered. A fan or blower system, probably of a suitable grade stainless steel, would have to be installed to withstand 1100°F gases. Alternately, the fuel stream could be blended with combustion air enroute to the fan (induced-draft type) so that the mixture temperature would be more favorable for the fan; but a flame arrestor would need to be employed in this case.

The transport conduit would require good insulation and structural support for materials' temperatures. Condensation of tar vapors (approximately 450-500°F) would have to be avoided so that ducts, fans, and burners would not be fouled. Other factors would need to be evaluated. At present production rates, one furnace could be fitted and tested for feasibility with a side stream of the 1100°F fuel mixture.

The incentive to consider the proposed change is the potential savings of about $125,000 per year in energy costs at present flow rates. Heat is now rejected at the rate of 5.2 million BTU per hour by cooling the mixture from 1100°F to 122°F; subsequent reheating toward furnace conditions absorbs the 5.2 million BTU per hour from the high cost producer gas. Added to the fuel savings, to arrive at the $125,000, there will be other, lesser savings:

Cooling water
Decanter heater steam
Nozzle and line cleaning steam
Liquor pumping
Tar pumping
Tar heating at the Boiler House
Atomizing steam at tar burners

The present difficulties of handling tar and other residuals in the decanter and firing equipment are not assessed here.

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* William L. Viar and John F. Filliben, "Energy Management Services," DuPont Education and Applied Technology Division, August 1975, pp. 81-82.

APPENDIX B

EVALUATION OF DUPONT PROPOSAL FOR ENERGY CONSERVATION IN GAS PRODUCER PROCESS HOLSTON ARMY AMMUNITION PLANT

Introduction

DuPont's Energy Management Report for Holston AAP, dated August 1975, contained an energy-conserving process change for the Gas Producer Facility that would result in significant savings. This proposed process change has been evaluated as to its technical and economic feasibility. The results of this evaluation along with recommendations are presented here for possible use in future Energy Conservation and Modernization Planning.

Feasibility of Proposal

Technical Considerations - The change proposed by DuPont would require the installation of a high-temperature gas distribution main from the discharge of the gas producers to the ketene furnaces in Buildings 7 and 20. The proposal does not include any details as to what configuration this gas distribution system might have, but it would most likely require two manifold systems similar to the existing collector mains. The DuPont report hits at potential problems resulting from entrained fly ash in the hot gas. Such problems will not only be possible, but will be very likely to occur based on previous operating experience of the gas producer facility and other fly ash handling systems in the plant. Any plans to incorporate the DuPont proposal into our facility should include the use of electrostatic precipitators or other high-efficiency particulate removing devices as close to the gas producer discharge as possible. The number and exact placement of these precipitators should be determined by the designer. It is assumed that the addition of high-efficiency fly ash collectors to the DuPont proposal will eliminate a redesign of the ketene furnaces. Obviously development work will be necessary to determine what effects the fly ash will have on the design and maintenance of the entire system and to determine the best method of solving any associated problems.

The relatively high gas temperatures that will exist in the new hot-gas system will present some special design problems. A not-so-rigorous analysis of the temperature drop in the gas distribution main between Building 10 and the ketene furnaces indicates that the gas temperature may drop from 1200°F to 600°F. Admittedly, a more exact calculation may show that the temperature drop will not be that great. However, the designer must keep this temperature drop to a minimum in order to maximize benefits from the new system. High temperature gas handling equipment will be required at all points in the system. The new gas main must be larger in diameter than the existing one to handle the same

amount of hot gas unless some pressurized storage and distribution system is devised. Special consideration must be given to insulation and supports for the new main. Fitting it into the existing building and pipe-supports could be difficult. In addition, some means of removing tar and fly ash from this gas main must be included in the design. The required length of the new main will most likely cause the settling of fly ash and the condensation of tar vapors. The result will be a plugged main if clean-out provisions are not made.

DuPont has suggested blending combustion air with the hot gas stream to reduce its temperature and thereby relax the high temperature requirement on the gas moving unit(s). This will not only be unsafe from an explosion standpoint, but it could present a tar condensation problem by lowering the gas temperature too much. This approach is therefore not recommended.

Entrained tar in the gas stream must also be considered in the design. A burner redesign may be required, and as stated before, a provision for tar clean-out and handling must be made not only in the main but in all equipment handling the gas.

No conclusions are made as to the possibility or impossibility of designing and implementing a change as proposed by DuPont. The comments above are intended to indicate that such a design will at best be costly to install and that the several unusual design requirements must be carefully considered. A pilot installation for hot gas distribution is considered to be the only means of determining if such a system is technically feasible.

Economic Considerations - The DuPont report claims that a savings of $125,000/yr could be realized at current production rates (approximately 150 million cu. ft./mo.). It is not clear from their report exactly what factors were considered in the computation of this figure or what the magnitude of the contribution from the "lesser savings" (Elimination of cooling water, decanter steam, tar handling, etc.) is.

Assuming that the proposal to eliminate cooling of the gas is technically feasible, calculations were made to determine what the savings would be considering all significant contributors. The following guidelines were used:

(1) The gas would reach the ketene furnaces at a temperature of approximately 600°F. (More exact calculation methods may show the temperature to be higher; however, with no final design available on the gas handling system, this figure appears to be conservative.) In the existing process, the gas temperature entering the burners is 120°F.

(2) The gas must be heated to approximately 1000°F before ignition.

(3) If the gas is not cooled, the tars are not removed and the heating value of the gas increases from approximately 160 BTU/SCF to

approximately 180 BTU/SCF. The value of the tar as a fuel from the existing process is considered.

(4) If the gas is not cooled, the following items of existing equipment would not be required: both primary and secondary scrubber/coolers, the tar decanters, the cascade cooling coils, and the tar and liquor handling systems. The existing gas collection and distribution system (including exhausters) would have to be replaced with a high temperature design good for handling $1200^{o}F$ gas. The elimination of these items of existing equipment will result in an annual savings of $60,000 in maintenance and operating costs. The new gas distribution system would cost approximately $750,000. Existing equipment has no salvage value.

Figure B-1 shows the relationship between annual savings in gas production and the average annual process heat requirement at the ketene furnaces. It should be noted that only the savings resulting from a reduced fuel requirement (made possible by a hotter fuel gas having a higher heating value) are considered. Obviously, the economic benefits to be realized from the proposed change are directly dependent on the gas production rate.

The calculations used for the graph in Figure B-1 did not consider other additional savings, the initial investment for the proposed change or the time-value of money. These relationships are presented in Figure B-2, which shows the Profitability Index versus Process Heat Requirement. For an average annual production rate such as that for FY-76, a profitability index between 1.0 and 2.0 might be expected. In comparison, the profitability index at maximum production would be approximately 7.0.

Disposition of Proposal

The changes required to implement the DuPont proposal amount to a major project under-taking. Because of this, it seems reasonable to consider what other alternatives exist for optimizing the procurement of fuel for the ketene furnaces before settling on this one approach. Over the last several years, a number of modernization schemes have been considered for the gas producer facility and/or the anhydride manufacturing process. The chart shown in Table B-1 compares a number of alternatives which are currently considered to have merit. Those alternatives which have received previous attention are:

No. 1 - Modernization of the existing facility by replacing the tar decanters and cooling coils - MOD Project 5793606 is underway; the next milestone will be to finalize the design criteria. The purpose of this project is to eliminate water pollution and reduce maintenance costs. In addition, a design is being made as a part of the FY-79 PS&ER Project to eliminate air

pollution by recycling bleed-off gas. No attempt is being made at present to improve efficiency or to alter the basic process.

No. 4 - Modernization of the acetic anhydride facility for the use of fuel oil instead of producer gas - MOD Project 5712077 was set up to perform a pilot study and prepare a design for making the fuel change. MOD Project 5742074 was set up to make the fuel conversion on 24 furnaces in Building 7. A design was finalized for the pilot study on Project 5712077; however, it and Project 5742074 were cancelled because of the fuel situation in December 1973. It is understood now that another MOD Project, 5862540, has been set up to essentially revive the conversion to fuel oil which was originally included in Project 5742074. The R. M. Parsons Company has recommended the use of fuel oil for X-Facility ketene furnaces.

No. 6 - Build a completely new gas producer plant of the most recent workable design - Picatinny Arsenal contracted Stanford Research Institute in 1974 to study the existing technology on gas production from coal to determine what process would be suitable for replacing the present gas producer facility. No formal report on this study has ever reached HDC. However, previous consultation with personnel at Picatinny has revealed the following: (1) A process for the production of synthetic natural gas (900^{+} BTU/cu. ft.) is not available in a useful size for HAAP and is not economically feasible. (2) One or more processes for the production of low to medium BTU gas (150-300 BTU/cu. ft.) were considered as possible replacement candidates; none were specifically recommended because proven final designs were not available. A pilot plant could be built at Holston AAP.

The proposal made by DuPont for elimination of the producer gas cooling phase should be evaluated in light of the other alternatives shown in Table B-1. This evaluation could best be made by an outside agency or firm which is highly knowledgeable of current coal gas production technology and combustion processes. In addition, all modernization efforts for both the anhydride manufacturing facility and the gas producer facility should be coordinated by the same individual or group. A total modernization plan should then be made which incorporates the results of an in-depth study of all the alternatives. The present approach of piecemeal modernization activity will not be economical and will not result in significant improvements to the facility in the areas of pollution abatement, maintainability, and energy conservation that will be needed to meet future requirements.

Summary and Recommendations

The DuPont proposal to eliminate the cooling phase of the gas producer process to conserve energy is thermodynamically sound, and the projected monetary savings are attractive. However, the design of the system

modifications will be unusually difficult because of high gas temperatures and the presence of entrained fly ash and tars in the gas. A pilot study of the design should be made before modifying the entire gas plant.

It is recommended that an overall study of several alternative modernization schemes, including the DuPont proposal, be made before submitting a project to incorporate this proposal. This study should be performed by an outside agency or firm highly knowledgeable and technically competent in current coal-to-gas conversion technology, coal carbonization technology, and general fuel and combustion technology. An overall modernization plan should then be prepared for both the anhydride manufacturing facility and the gas (or fuel) production facility under the coordination of a single head. These facilities can be truly modernized only when the interests of improved maintainability, pollution abatement, and energy conservation are considered simultaneously.

Table B-1. Comparison of alternatives

Gas Production

No. Alternative	Technology	Earliest Time On Line	Installed Cost (In $1000's)	Relative Cost* of Fuel Gas	Pollution Impact	Energy Waste	Remarks
(1) Existing plant	Existing	Currently Operating	None (Mod. Project Cost $500)	1.00	Some water and air pollution	Excessive	FY-79 MOD Projects in progress will eliminate water poll. PS&ER Proj. will eliminate air.
(2) Existing plant W.O. Gas Cooling (DuPont Proposal)	Workable design not available; 3-5 yrs. away	1981-1983	750	0.88	Some air pollution	Minimal	Air pollution will not be corrected by this change in process (see above).
(3) Existing plant but use coke instead of coal	Coke fueled producers used extensively in years past; use in HAAP producers unproven.	1977-1978	None	0.71	None	Approx. same as for existing plant	Will eliminate need for tar decanters and tar handling. Hot gas system possible modification.
(4) Use fuel oil to fire ketene furnace and eliminate Bldg. 10	Existing	1983	2,923	1.24	None	Minimal	Previous MOD Proj. in pilot stage; cancelled due to fuel situation.
(5) Install Coke Plant at Area "A". Use by-product gas in Ketene Furnaces & use coke in all boilers instead of coal	Existing (no alternation to furnaces or boilers required.	1983	4,500	0.73	None	Minimal	Advantage would be that only one grade of coal would be required for whole plant
(6) Build new Gas Producer Facility	Existing for some processes on market.	1983-1985	6,000	1.00	None	Minimal	Probably best long range solution because of fuel situation

*Does not include cost of modifications or new facilities

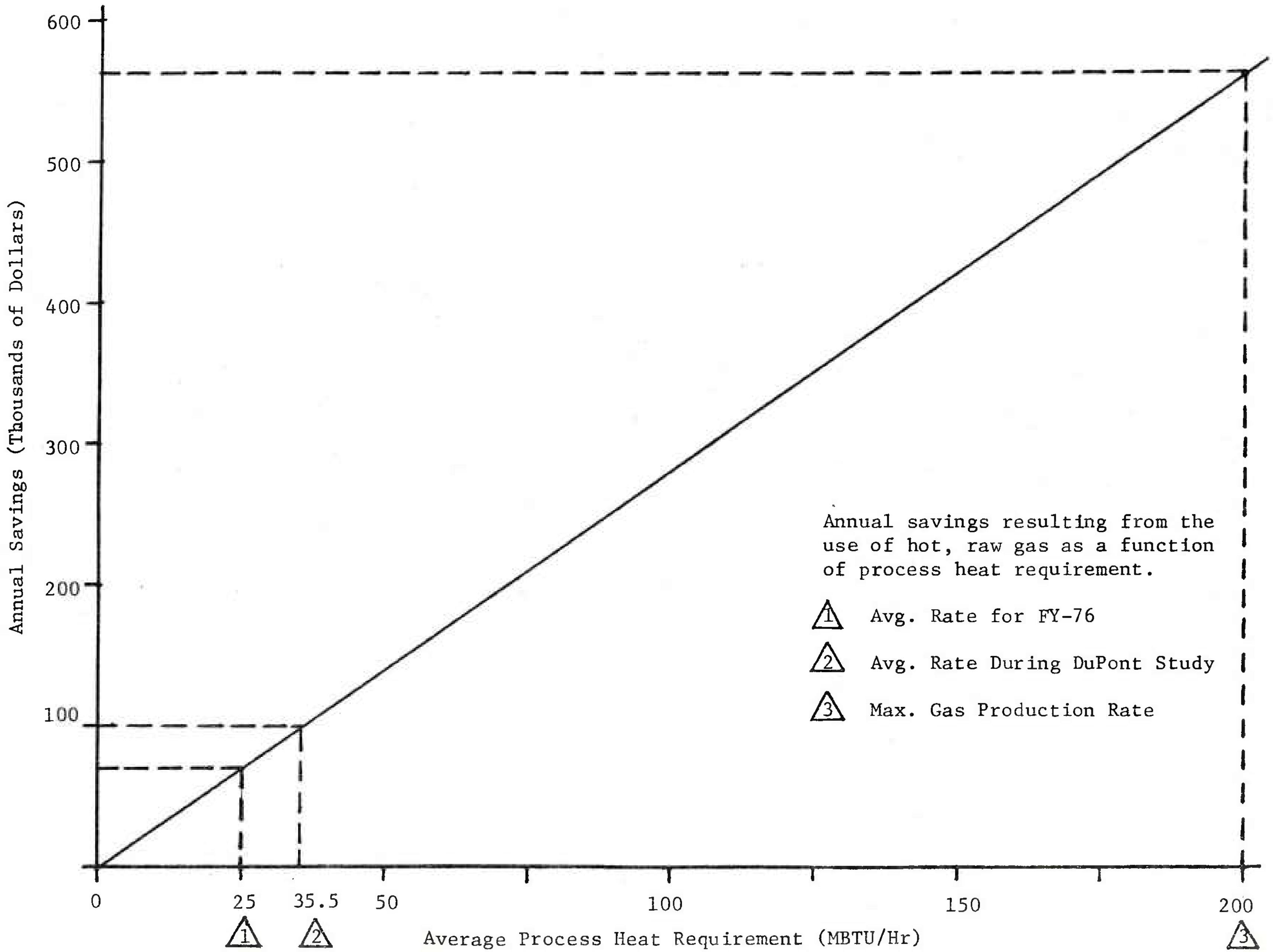

Figure B-1. Relationship between annual gas production savings and average process heat requirement at ketene furnaces

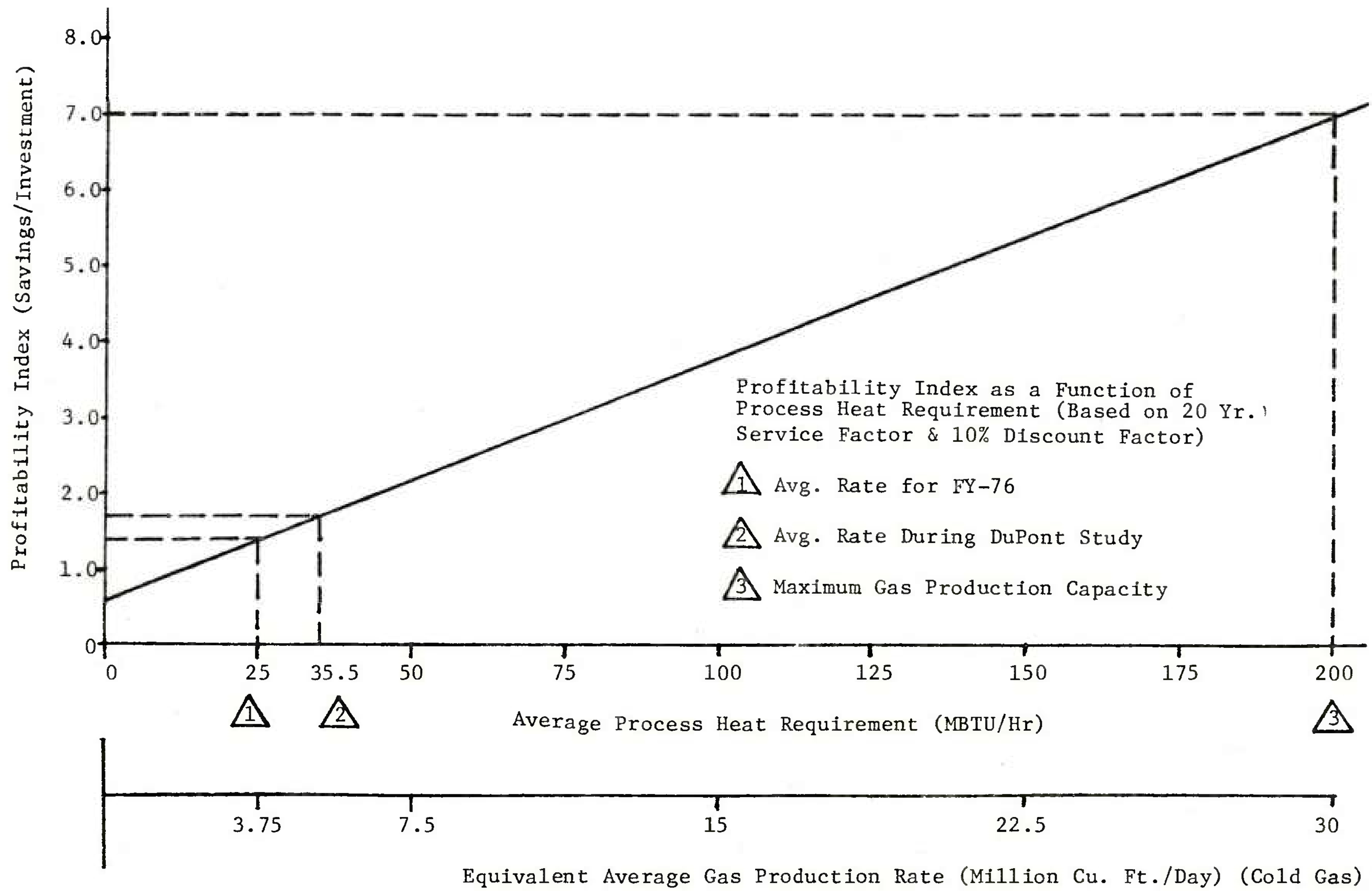

Figure B-2. Relationship between probability index and average process heat requirement with equivalent average gas production rate

APPENDIX C

EXPERIMENTAL: BASELINE INFORMATION

Table C-1. Producer gas analysis (baseline), percent volume and BTU values (cool scrubbed gas)

Component	Sample 22-1	Sample 22-2	Sample 22-3	Sample 22-4	Sample 22-5	Average
Percent Volume (Normalized)						
H_2	17.77	17.78	15.63	16.04	17.02	16.85
O_2	0.64	0.76	3.41	3.18	0.73	1.74
N_2	51.45	59.73	54.24	54.50	58.25	55.63
CH_4	1.60	1.74	1.63	1.75	1.84	1.71
CO	17.57	18.67	17.64	18.44	19.70	18.40
CO_2	10.39	2.75	6.81	5.55	1.81	5.46
C_2H_4	0.34	0.34	0.41	0.34	0.40	0.37
C_2H_6	0.25	0.22	0.22	0.21	0.26	0.23
BTU Values/ft.^{3}						
H_2	57.73	51.27	50.78	52.11	55.30	53.44
CO	56.51	60.04	56.73	59.30	63.36	59.19
CH_4	16.19	17.61	16.50	17.71	18.62	17.33
C_2H_4	5.49	5.49	6.62	5.49	6.46	5.91
C_2H_6	4.47	3.94	3.94	3.76	4.65	4.15
Total	140.38	138.35	134.57	138.37	148.39	140.0

Table C-2. Properties of cold, scrubbed producer gas

Component	Average Volume Percent	Component Mol. Wt.	Weight Percent	Specific Heat @ 120°F, BTU/Lb°F	Density @ 120°F, Lb/Ft^3	Viscosity* @ 120°F, μ Poise
H_2	16.85	2	1.39	4.8 E-02	9.5 E-04	94
O_2	1.74	32	2.29	4.0 E-03	1.6 E-03	220
N_2	55.63	28	63.67	1.6 E-01	4.3 E-02	189
CH_4	1.71	16	1.10	6.0 E-03	7.5 E-04	116
CO	18.40	28	21.05	5.2 E-02	1.4 E-02	190
CO_2	5.46	44	9.81	2.0 E-02	6.7 E-03	152
C_2H_4	0.37	28	0.41	2.0 E-03	2.8 E-04	98
C_2H_6	0.23	30	0.28	1.0 E-03	1.9 E-04	110

Calculated Properties

Producer Gas Molecular Weight = 24.47
Producer Gas Specific Heat @ 120°F (580°R) = 0.294 $\frac{BTU}{Lb^{o}F}$
Producer Gas Density @ 120°F (580°R) = 0.067 Lb/Ft^3
Producer Gas Viscosity @ 120°F (580°R) = 181.1 μ Poise

*Perry's Chemical Engineer's Handbook, Fourth Edition, pp. 3-196 and 3-197.

APPENDIX D

EXPERIMENTAL: OPERATIONAL EVALUATION

Table D-1. Uncooled producer gas pilot plant (cold, scrubbed gas)

Time	Producer Gas Temperatures						Prod. Gas Press.		Coil H_2O Temps.		Air Flow	P.G. Flow	Stack Temp.
	TIR 1	TIR 3	TIR 5	TI 2-1	TI 2-2	TI 2-4	PI 2	PI 5	Inlet	Exit	SCFM	ACFM	TIR 21
1:00 p.m.	-	113	113	113	113	113	20.7	5.2	46	56	75	81.5	460
2:00	-	115	115	132	115	115	20.9	4.9	46	56	84	83.5	710
3:00	-	121	121	125	123	121	19.7	5.1	46	59	84	77.9	820
4:00	-	128	128	132	128	128	19.4	5.1	46	61	84	75.5	855
5:00	-	129	129	133	130	129	20.9	5.5	47	62	84	81.1	887
6:00	-	132	132	131	132	132	21.3	5.7	47	62	105	81.9	880

Notes:

1. Temperatures are ^{o}F.
2. Pressures are inches of water.
3. PI-2 measured at booster gas fan discharge.
4. PI-5 measured at burner inlet.

Table D-2. Uncooled producer gas pilot plant (hot, crude gas)--test 1

Time	Producer Gas Temperatures						Prod. Gas Press.		Coil H_2O Temps.		Air Flow	P.G. Flow	Stack Temp.
	TIR 1	TIR 3	TIR 5	TI 2-1	TI 2-2	TI 2-4	PI 2	PI 5	Inlet	Exit	SCFM	ACFM	TIR 21
1:00 p.m.	725	-	-	225	160	176	17.9	4.5	46	46	85	88.3	660
2:00	1010	-	-	543	334	285	15.4	4.1	46	58	85	76.2	770
3:00	1018	-	-	652	476	385	15.8	4.5	47	61	84	76.2	833
4:00	1000	371	369	585	567	503	17.2	5.4	48	63	84	79.2	835

Notes:

1. Temperatures are ^{o}F.
2. Pressures are inches of water.
3. PI-2 measured at booster gas fan discharge.
4. PI-5 measured at burner inlet.

Table D-3. Uncooled producer gas pilot plant (hot, crude gas)--test 2

Time	Producer Gas Temperatures						Prod. Gas Press.		Coil H_2O Temps.		Air Flow	P.G. Flow	Stack Temp.
	TIR 1	TIR 3	TIR 5	TI 2-1	TI 2-2	TI 2-4	PI 2	PI 5	Inlet	Exit	SCFM	ACFM	TIR 21
10:30 a.m.	835	165	158	258	181	199	19.3	4.9	47	60	87	82.8	515
11:00	1015	210	208	435	300	295	16.7	4.7	47	60	87	71.2	820
11:30	1022	278	275	507	411	392	17.1	4.9	47	60	87	76.1	805
12:00 N.	1020	340	340	571	500	465	17.5	5.7	47	61	87	77.3	795
12:30 p.m.	1016	391	386	599	535	517	17.4	5.7	48	69	87	78.6	845
1:00	1039	423	415	612	547	547	560	17.7	48	48	80	81.9	835

Notes:

1. Temperatures are ^{o}F.
2. Pressures are inches of water.
3. PI-2 measured at booster gas fan discharge.
4. PI-5 measured at burner inlet.

Table D-4. Producer gas analyses, percent volume and BTU values (hot unscrubbed gas)--test 2

Component	Sample 29-1 [a]	BTU/ft^3	Sample 29-2 [a]	BTU/ft^3	Sample 29-3 [a]	BTU/ft^3	Sample 29-4 [a]	BTU/ft^3	Component Average [a]	BTU Average
H_2	18.06	56.68	18.51	60.14	18.28	59.39	18.86	61.28	18.43	59.87
O_2	0.68	-	1.12	-	0.63	-	0.68	-	0.78	-
N_2	52.40	-	51.33	-	51.78	-	53.29	-	52.20	-
CH_4	2.06	20.85	2.18	22.06	2.13	21.56	2.18	22.06	2.14	21.63
CO	18.43	59.24	19.12	61.49	20.28	65.22	20.22	65.03	19.51	62.75
CO_2	7.83	-	7.20	-	6.32	-	4.16	-	6.38	-
C_2H_4	0.32	5.16	0.30	4.84	0.35	5.65	0.36	5.81	0.33	5.37
C_2H_6	0.23	4.11	0.25	4.47	0.23	4.11	0.26	4.65	0.24	4.34
Total		148.04		153.00		155.93		158.83		153.96

[a] Percent volume (normalized).

Cool Scrubbed Gas [b]

Component	Percent Volume Normalized	BTU Values/ft.^{3}
H_2	15.97	51.89
O_2	3.66	-
N_2	55.40	-
CH_4	1.60	16.19
CO	17.63	56.70
CO_2	5.28	-
C_2H_4	0.29	4.68
C_2H_6	0.17	3.04
	Total	132.5

[b] Sample collected during operations with the hot producer gas.

Table D-5. Uncooled producer gas pilot plant (hot, crude gas)--test 3

Time	Producer Gas Temperatures						Prod. Gas Press.		Coil H_2O Temps.		Air Flow	P.G. Flow	Stack Temp.
	TIR 1	TIR 3	TIR 5	TI 2-1	TI 2-2	TI 2-4	PI 2	PI 5	Inlet	Exit	SCFM	ACFM	TIR 21
9:00 a.m.	960	283	278	671	457	450	17.8	3.3	45	53	86	87.7	535
9:30	965	398	385	713	521	540	18.0	5.0	46	56	86	86.1	684
10:00	968	442	420	722	534	582	18.4	5.1	46	56	86	90.1	646
10:30	970	493	470	730	546	617	18.4	4.5	46	57	85	95.9	703
11:00	-	-	-	-	-	-	-	-	-	-	-	-	-
11:30	965	455	435	728	555	624	18.6	4.1	46	55	85	96.5	570

Notes:

1. Temperatures are ^{o}F.
2. Pressures are inches of water
3. PI-2 measured at booster gas fan discharge.
4. PI-5 measured at burner inlet.
5. System tripped at 10:55; probably caused by fly ash.
6. System tripped at 11:52; would not restart.

Table D-6. Uncooled producer gas pilot plant (hot, crude gas)--test 4

Time	Producer Gas Temperatures						Prod. Gas Press.		Coil H_2O Temps.		Air Flow	P.G. Flow	Stack Temp.
	TIR 1	TIR 3	TIR 5	TI 2-1	TI 2-2	TI 2-4	PI 2	PI 5	Inlet	Exit	SCFM	ACFM	TIR 21
9:30 a.m.	880	197	197	425	223	245	17.4	3.4	42	54	89	77.6	490
10:00	986	312	311	625	361	411	16.7	3.4	43	54	88	83.7	545
10:30	990	379	379	680	430	490	17.4	4.2	43	55	88	87.2	684
11:00	985	432	441	695	475	560	17.9	4.2	43	56	88	92.9	684
11:30	986	490	473	780	508	605	18.2	4.2	43	85	87	96.4	651
12:00 N	985	533	508	755	525	623	18.4	4.1	44	95	86	99.5	641
12:30 p.m.	985	550	522	755	543	625	18.4	4.1	44	94	86	100.9	638
1:00	980	575	538	735	560	620	18.4	3.9	44	94	86	102.0	640
1:30	985	610	540	730	570	616	18.8	2.9	44	90	102	109.4	666
2:00	980	625	540	710	565	605	19.6	2.9	44	90	101	113.4	640
2:30	976	586	533	695	565	593	19.8	2.9	44	92	102	114.1	678
3:00	985	565	525	680	562	580	19.9	3.1	44	94	102	113.4	704
3:30	985	555	577	667	560	572	19.7	3.4	44	95	102	111.0	704
4:00	995	555	515	675	560	566	19.7	3.5	44	98	84	109.4	706
4:30	992	550	505	685	560	565	19.7	3.4	44	73	85	109.9	650
5:00	990	540	505	700	555	555	19.7	3.4	44	73	85	109.9	665
5:30	995	538	502	690	551	551	19.8	3.3	44	73	85	110.7	655
6:00	990	535	500	678	550	542	19.8	3.2	44	73	86	111.0	658
6:30	987	530	495	675	545	540	20.1	3.1	44	71	86	112.4	628
7:00	987	525	482	677	540	528	20.1	2.0	44	67	85	117.6	595

Notes:

1. Temperatures are ^oF.
2. Pressures are inches of water
3. PI-2 measured at booster gas fan discharge.
4. PI-5 measured at burner inlet.
5. System tripped at 4;17 p.m.; started back at 4:18 p.m. false high pressure on PI-2.

Table D-7. Producer gas analyses, percent volume and BTU values (hot, unscrubbed gas)--test 4

Component	Sample 5-1*	BTU/ft^3	Sample 5-2*	BTU/ft^3	Sample 5-3*	Sample 5-4*	BTU/ft^3	Component Average*	BTU Average
H_2	18.12	58.87	18.70	60.76	18.03	17.92	58.22	18.24	59.28
O_2	1.22	-	0.71	-	0.61	0.64	-	0.86	-
N_2	51.29	-	52.76	-	49.66	51.32	-	51.79	-
CH_4	1.88	19.03	1.83	18.52	2.13	2.03	20.54	2.87	19.36
CO	20.25	65.12	20.59	66.22	19.98	20.31	65.32	20.38	65.55
CO_2	6.77	-	4.80	-	Insufficient Sample	7.28	-	6.28	-
C_2H_4	0.27	4.36	0.35	5.65	Insufficient Sample	0.29	4.68	0.30	4.90
C_2H_6	0.20	3.58	0.26	4.65	Insufficient Sample	0.22	3.94	0.23	4.06
Totals		150.96		155.80			152.70		153.15

*Percent Volume (Normalized)

Component	Percent Volume Normalized	BTU Values/ft^3
H_2	14.89	48.38
O_2	3.94	-
N_2	57.11	-
CH_4	1.64	16.60
CO	17.54	56.41
CO_2	4.43	-
C_2H_4	0.28	4.52
C_2H_6	0.17	3.04
	Total	128.95

Sample collected during operation with the hot producer gas.

Table D-8. Producer gas analyses, percent volume and BTU values (hot, unscrubbed gas)--test 5

Component	Sample 11-1*	BTU/ft^3	Sample 11-2*	BTU/ft^3	Sample 11-3*	BTU/ft^3	Sample 11-4*	BTU/ft^3	Component Average*	BTU Average
H_2	18.08	58.74	19.76	64.20	17.97	58.38	18.22	59.20	18.51	60.13
O_2	1.20	-	0.64	-	0.63	-	0.64	-	0.78	-
N_2	49.06	-	49.33	-	49.21	-	50.33	-	49.48	-
CH_4	1.71	17.31	1.85	18.72	1.78	18.01	1.63	16.50	1.74	17.64
CO	19.12	61.49	20.21	65.00	19.34	62.20	19.69	63.32	19.59	63.00
CO_2	9.97	-	7.20	-	10.14	-	8.65	-	8.99	-
C_2H_4	0.55	8.88	0.58	9.36	0.60	9.68	0.54	8.72	0.57	9.16
C_2H_6	0.30	5.37	0.43	7.69	0.35	6.26	0.29	5.19	0.34	6.13
Totals		151.79		164.97		154.53		152.93		156.06

*Percent volume (normalized)

Cool Scrubbed Gas

Component	Percent Volume Normalized	BTU Values/ft^3
H_2	15.50	50.20
O_2	3.34	-
N_2	53.29	-
CH_4	1.59	16.09
CO	17.21	55.19
CO_2	8.53	-
C_2H_4	0.53	8.55
C_2H_6	0.32	5.72
	Total	135.75

Sample collected during operation with the hot producer gas.

APPENDIX E

EXPERIMENTAL: PROCESS DATA ANALYSIS

Table E-1. Crude producer gas properties as a function of temperature*

Temperature °F	Temperature K	Density Lbs./ft^3	Density kg/m^3	Specific Heat BTU/Lb.°F	Specific Heat kJ/kgK	Viscosity μ poise	Viscosity Pa . s
100	311	0.061	0.977	0.291	1.218	174.7	1.75E-05
200	366	0.051	0.817	0.297	1.243	198.2	1.98E-05
300	422	0.044	0.705	0.301	1.259	220.6	2.21E-05
400	478	0.039	0.625	0.305	1.276	243.1	2.43E-05
500	533	0.035	0.561	0.310	1.297	264.0	2.64E-05
600	589	0.032	0.515	0.316	1.322	283.7	2.84E-05
700	644	0.029	0.465	0.321	1.343	303.0	3.03E-05
800	700	0.027	0.432	0.326	1.364	323.0	3.23E-05
900	755	0.025	0.400	0.331	1.385	339.6	3.40E-05
1000	811	0.023	0.368	0.335	1.402	359.5	3.60E-05
1100	866	0.021	0.336	0.341	1.427	373.8	3.74E-05

*This data was calculated based upon gas chromatography analyses of the hot, crude gas samples.

Table E-2. Uncooled producer gas pilot material balance based on one hour of operation

Stream Description	Producer Gas		Combustion Air		Propane		Water		Flue Gas	
	Lbs.	kg	Lbs.	kg	Lbs.	kg	Lbs.	kg	Lbs.	kg
Producer Gas From Unit No. 10 to Booster Fan	552.0	250.6	-	-	-	-	-	-	-	-
Producer Gas Flow to Eclipse Burner	224.5	101.9	-	-	-	-	-	-	-	-
Producer Gas Flow Thru 2 Inch By-Pass	161.9	73.5	-	-	-	-	-	-	-	-
Producer Gas Losses at Booster Fan Shaft*	165.6	75.2	-	-	-	-	-	-	-	-
Propane Flow to Burner Pilot	-	-	-	-	1.8	0.8	-	-	-	-
Combustion Air to Pilot Furnace	-	-	490.9	222.8	-	-	-	-	-	-
Water Flow to Furnace Coil	-	-	-	-	-	-	7506	3407	-	-
Flue Gas	-	-	-	-	-	-	-	-	717.2	325.6

*Estimated as 30% of the total flow from the Unit No. 10 Gas Producer.

Table E-3. Crude gas BTU value versus cold gas BTU value

Component	Average Crude Gas Analysis[a]	Average Cold Gas Analysis[a]	Average Crude Gas BTU Value[b]	Average Cold Gas BTU Value[b]
H_2	18.24	14.89	59.28	48.38
O_2	0.86	3.94	-	-
N_2	51.79	57.11	-	-
CH_4	2.87	1.64	19.36	16.60
CO	20.38	17.54	65.55	56.41
CO_2	6.28	4.43	-	-
C_2H_4	0.30	0.28	4.90	4.52
C_2H_6	0.23	0.17	4.06	3.04
			153.15	128.95

[a] Volume Percent (Normalized)
[b] BTU Per Cubic Foot

SPECIAL TERMS

ACFM	Absolute cubic feet per minute
FE	Flow element
PG	Producer gas
PI	Pressure indicator
SCFM	Standard cubic feet per minute
TI	Temperature indicator
TIR	Temperature indicator recorder

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